IS TESTOSTERONE THE HORMONE OF DESIRE?

FOR SOME WOMEN, SOME OF THE TIME

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Psychology

The University of Utah

May 2014

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

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ABSTRACT

Although testosterone (T) has been dubbed the "hormone of desire," the link between T and sex drive has proven inconsistent among women. The mixed pattern of findings suggests that woman vary in the degree to which changes in T correspond to changes in sex drive (i.e., the T-drive linkage). Yet, to date no one has examined why this variation exists. The current study sought to answer 2 questions: First, within each individual woman, does T-drive linkage change as a function of ovulation? Second, is the overall degree of T-drive linkage higher in women with greater sexual motivation, greater average T, or greater daily variability in T, and among lesbian, bisexual or heterosexual women? We further explored how between-person and within-person characteristics interact to shape the T-drive linkage. To do this, we assessed daily T and daily sex drive over the middle 2 weeks of the menstrual cycle in a sample of 157 heterosexual, lesbian, and bisexual women. Multilevel modeling analyses demonstrated that lesbian and bisexual women showed a significant T-drive linkage, but only following ovulation, whereas heterosexual women had a significant T-drive linkage, but only prior to ovulation. Moreover, women with higher average T levels showed an inverse T-drive linkage prior to ovulation and a positive T-drive linkage following ovulation, whereas women with lower average T levels did not show a significant T-drive linkage during any ovulatory phase. Results suggest that considering menstrual cycle timing and trait-like characteristics are key to understanding variation in the T-drive linkage.

To my sister and best friend, who have helped me articulate the ideas presented in this paper, and who shared their experiences in an effort to provide me with real-world examples for me to ponder in writing this thesis.

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ACKNOWLEDGMENTS

I would like to express my deepest reverence and appreciation for my advisor, Dr. Lisa Diamond, who has the substance of a genius, a spirit of adventure, and a perfect mentorship style balanced by dedication and zeal. Without her continual guidance, her persistent belief in my ability, and her direct, constructive criticism, this thesis would not have been possible.

I would like to thank my committee members, Drs. Dave Huebner and Don Strassberg, who have persistently challenged me academically and intellectually. Their attentiveness to pragmatic details has enhanced my intellectual pursuits in research. I have the deepest appreciation for their generosity of their time and professional guidance. I would like to thank Dr. Brian Baucom who was kind enough to spend many hours with me explaining analytic procedures and broaden my understanding of complicated data. I would also like to thank the American Institute of Bisexuality, who funded this research.

I would like to thank my close colleagues and friends who have listened to multiple iterations of my logical argument. Finally, I would like to express my deepest gratitude for my mother, sister, brother, and best friend, who have unconditionally encouraged me with love, guidance, and inspiration throughout this process and without whom this thesis would not have come to fruition. A special thank you to my father, who entertained my desire to understand concepts in mathematical form.

INTRODUCTION

Testosterone (T) has historically been dubbed the "hormone of desire." Although researchers have found that T reliably enhances men's sex drive (i.e., sexual motivation, typically indicated by the frequency of one's sexual thoughts and arousal; Baumeister, Catanese, & Vohs, 2001), T's influence on women's sex drive remains unclear (see Bancroft & Graham, 2011). Nonetheless, news headlines, online blogs, and medical webpages that discuss women's sex drive all convey the same message: low levels of T are associated with low sex drive, whereas high levels of T are associated with high sex drive. Additionally, women complaining of low sex drive have been regularly prescribed T therapy (i.e., exogenous administration of supplemental T) for over 40 years, despite a lack of FDA approval (Margo & Winn, 2006). Although researchers, medical providers, and the media assume that higher levels of T should be robustly associated with higher levels of sex drive, the degree of linkage between T and sex drive has proven inconsistent from study to study (see Bancroft & Graham, 2011).

One potential interpretation of this mixed pattern of findings is that the degree of linkage between T and sex drive proves inconsistent from woman to woman. In other words, one woman's fluctuations in T, from day to day and moment to moment, may directly correspond to fluctuations in her sex drive. This woman can be said to show high T-drive linkage. Another woman's day-to-day and moment-to-moment fluctuations in T may show no relationship to fluctuations in her sex drive, and she can be said to show

low T-drive linkage. T-drive linkage may therefore represent a relatively stable characteristic that varies from woman to woman. T-drive linkage might also vary within a particular woman, such the same woman might show stronger T-drive linkage at some points in time than at others. Given that a woman's overall sex drive tends to vary as a function of ovulation, T-drive linkage might also vary as a function of ovulation. What is the relevance of such variation? Might women with high versus low T-drive linkage have other distinguishing sexual characteristics? Might ovulation-related changes in T-drive linkage be more evident in some women than others? Addressing these questions would not only provide insight into the basic psychobiology of female sexuality, but would also provide important information regarding the clinical treatment of women with low sex drive, potentially elucidating why some women benefit more than others from the administration of supplemental T.

Hence, the aim of the current study was to identify between-person and within-person factors that predict variation in women's day-to-day T-drive linkage. We assessed daily T and daily sex drive over a 14 day period in a sample of 157 heterosexual, lesbian, and bisexual women. The inclusion of sexual-minority (i.e., nonheterosexual) women represents an important contribution of this research: Previous research on T and sex drive has focused exclusively on heterosexual women, despite evidence that sexual-minority women sometimes show different patterns of association between gonadal hormones and sexual motivation than do heterosexual women (Diamond & Wallen, 2011). We sought to answer 2 questions: First, within each individual woman, does T-drive linkage change as a function of ovulation? In other words, might women show lower T-drive linkage around the time of ovulation than at other times? Second, is the

overall degree of T-drive linkage higher in women with greater average sex drive, greater average T, or greater daily variability in T? We also planned to explore potential interactions between within-person and between-person sources of variation, such as the possibility that between-person differences in T-drive linkage only become evident during ovulation.

Testosterone and Sex Drive

A number of studies have examined which sexual behaviors individuals consider to be "having sex" (e.g., Sanders & Reinisch, 1999). These studies all asked individuals to decide, for each of many sexual behaviors, whether or not they would say they had "had sex" if that was the most intimate behavior in which they engaged. Though there was some disagreement among these studies regarding how often some behaviors were considered "sex" (e.g., for oral-genital stimulation, 23-40%, and for manual-genital stimulation, 11-35%), other behaviors were rather uniformly considered to be sex (e.g., penile-vaginal intercourse) and not sex (e.g., deep kissing). The reason for this disagreement about some behaviors is not clear since none of these studies asked participants for an explanation for their answers.

Findings for gender have been inconclusive. Generally, when rank ordering the behaviors from least to most likely to be considered sex, the findings look similar between men and women (e.g., Randall & Byers, 2003); however, one pattern of gender differences has been identified: Men were more likely than women to label less sexually intimate behaviors (e.g., breast stimulation) as sex, whereas women were more likely than men to label more intimate (e.g., oral-genital stimulation) behaviors as sex (Pitts &

Rahman, 2001; Trotter & Alderson, 2007).

Some studies also found a number of (often quite complex) individual differences that appear to influence whether or not one labels a behavior as "having sex." One such difference is the extent of an individual's sexual experience. Sanders and Reinisch (1999) found that when someone has experienced oral-genital contact, but not penile-vaginal intercourse, they were less likely to label oral-genital contact as sex. An even more complicated relationship was reported by Byers, Henderson, and Hobson (2009): For males (but not for females), less sexual experience was associated with a greater likelihood of defining as sex behaviors in which both partners' genitals were being stimulated simultaneously (e.g., penile-vaginal intercourse) and a lower likelihood of defining as sex those behaviors involving only one person's genitals (e.g., manual-genital stimulation) and behaviors without genital stimulation (2009). Other studies, however, have not found that sexual experience mattered (Randall & Byers, 2003; Trotter & Alderson, 2007). Given these inconsistent findings, the current study explored this issue further. Specifically, we examined how more overall sexual experience impacted an individual's likelihood of defining a behavior as sex.

Byers et al., (2009) also examined religiosity as a possible influence on judgments about sex. They found that for males (but not females) greater religiosity was associated with an increased likelihood of labeling as sex behaviors in which both partners' genitals were being stimulated simultaneously than those involving only one person's genitals and those not including the genitals. However, they discuss that they did not have access to a diverse religious group, and that the group that labeled religion as "very important" was extremely small. They called for religiosity to be examined with a more diverse sample.

The current study had access to a wide range of self-identified religiosity among students, so we examined the influence of religious importance on definitions of sex.

Within-Person Variability in the Link between T and Sex Drive

As reviewed above, numerous studies have assessed T-drive linkage by taking a single assessment of women's T levels, a single assessment of their sex drive, and correlating these assessments. Yet, this strategy overlooks the possibility that the linkage between a woman's T levels and her sex drive might be higher on some days than on others, potentially due to the hormonal changes associated with ovulation. The notion that the relation between T and sex drive may vary as a function of ovulation is supported by previous research demonstrating that both T and sex drive show variation across the menstrual cycle. As shown by Burger (2002), T levels typically increase during the follicular phase (i.e., the period after menstruation and prior to ovulation), reach a crest around ovulation, and then gradually decline during the luteal phase (i.e., the period following ovulation and before menstruation). Although T shows additional day-to-day variation that is not accounted for by the menstrual cycle (Celec et al., 2007), this variation appears to be greatest during the middle 2 weeks over the cycle (Vermeulen & Verdonck, 1976).

Sex drive also varies across the menstrual cycle (e.g., Wallen, 1995), albeit less consistently than T. Specifically, women's sex drive is highest around ovulation (e.g., Harvey, 1987; Pillsworth, Haselton, & Buss, 2004; Roney & Simmons, 2013; Stanislaw & Rice, 1988; Wallen, 2001) and typically reaches a low point in the final third of the cycle (e.g., Roney & Simmons, 2013). Similar to the day-to-day variation found in

women's T levels, women's sex drive also shows day-to-day variation that is not accounted for by the menstrual cycle (Diamond, 2012). Given that both T and sex drive show ovulation-related variability, it is likely that the degree of linkage between ongoing changes in T and ongoing changes in sex drive may change before, during, and after ovulation.

Notably, studies correlating single measures of T and single measures of sex drive have found that these correlations vary as a function of ovulation. For example, Schreiner-Engel, Schiavi, Smith, and White (1981) measured women's T levels and their self-reported sexual arousal to erotic stimuli at three different times: during the follicular phase (before ovulation), during ovulation, and during the luteal phase (after ovulation). Although none of the correlations between T and subjective sexual arousal were statistically significant, the correlation coefficients were positive only during the ovulatory phase. This suggests the possibility that T-drive linkage might be stronger during ovulation than either before or after. Moreover, this study also examined whether women whose T levels were low or high showed differences in physiological (genital) sexual arousal across the three time-points. They found that women with higher T women showed significantly higher genital arousal, but only during the luteal phase (i.e., after ovulation). Although this study used single measures of T and sexual arousal, rather than assessments of naturally-occurring, ongoing variation in both T and sex drive, the findings suggest that the linkage between daily fluctuations in T levels and daily fluctuations in sex drive might be highest during or after ovulation. There are several important methodological considerations for studies examining individuals' definitions of sex, and each will be considered in the context of previous research.

Between-Person Variability in the Link between T and Sex Drive

Previous research indicates that the degree of linkage between T and sex drive might be stronger for women than for others, even after controlling for ovulation-related variability (Bancroft & Graham, 2011; Graham, Bancroft, Doll, Greco, & Tanner, 2007). For example, Graham et al. (2007) administered oral contraceptives to healthy premenopausal women to induce reductions in endogenous T levels. Both baseline and posttest measurements of T and sex drive were measured during the ovulatory period. After having their T levels artificially lowered by oral contraceptives, some women reported decreases in their sex drive, some women reported increases, and some women reported no changes at all. Because this study was confined to the ovulatory phase, it is not known whether the same effects (in the same women) would also be observed before and after ovulation, or whether they are specific to ovulation.

The reason that some women may show stronger T-drive linkage than others remains unknown. One possibility is that individual differences in the T-drive linkage may be systematically linked to certain hormonal and sexual characteristics of women, such as trait-like variation in overall T or overall sex drive.

Individual Differences in Sex Drive/Sexual Motivation

By definition, women with higher sex drives become sexually aroused more easily than women with lower sex drives (Lippa, 2007; Lippa, 2006). Hence, women with higher sex drives may be more responsive to various forms of influence that enhance sexual motivation, one of which is T. Hence, women with higher sex drives may have a higher T-drive linkage than women with lower sex drives. Although no previous research

has tested this possibility with regard to the linkage between daily T and daily sex drive, previous research has examined whether correlations between average T and average sex drive are weaker for subgroups of women with lower overall sex drives (e.g., Bancroft, Davidson, Warner, & Tyrer, 1980). For example, Riley and Riley (2000) investigated whether the relation between average T (measured once during ovulation) and average sex drive (measured daily, then averaged across 1 month) differed among women with extremely low levels of sex drive versus "normal" levels of sex drive. Among women with normal levels of sex drive, women with higher average T had higher average sex drive, whereas among women with low levels of sex drive, those with higher average T did not have higher average sex drive. Laboratory studies have yielded similar results. For example, Heiman et al. (2011) found that among women with normal or high sex drives, those with higher levels of salivary T were more sexually responsive to erotic stimuli. However, among women with low sex drives, who met the clinical criteria for hypoactive sexual desire disorder, those with higher levels of T were actually less sexually responsive to erotic stimuli. These findings suggest that women with higher sex drives may show a stronger positive association between changes in T and changes in sex drive than women with lower sex drives.

Individual Differences in Average T Levels

Women with higher versus lower average T levels may also show differences in the T-drive linkage. In men, studies have found that there is a ceiling effect in the link between T and sex drive. Once T levels reach a certain level, additional increases in T do not appear to be associated with additional increases in sex drive. This may be true for

women as well (Alexander & Sherwin, 1993), in which case women with lower average levels of T should show a stronger T-drive linkage (Bancroft & Graham, 2011). Yet, the most rigorous test of this hypothesis has not found convincing evidence to support this argument. In the Graham et al. (2007) study (reviewed above), between-person correlations of T and sex drive were not significant prior to or following a substantial reduction in T levels. Additionally, after 3 months of oral contraceptive use, women who reported thinking about sex less than several times a week were not disproportionately likely to be in the "low T group."

Another possibility is that there are "floor effects" in the link between T and sex drive. In other words, women may require a certain minimum level of T in order to evidence any association between T and sex drive. If this were the case, then women with higher average T levels would show a stronger T-drive linkage. This possibility is supported by research that measures endogenous T levels and sex drive. For example, in the above-mentioned study by Schreiner-Engel et al. (1981), the correlations between T and sexual arousal were positive only during ovulation, which is the point in the menstrual cycle when T is highest. Similarly, women with higher baseline levels of T showed larger increases in sexual arousal to erotic stimuli (Goldey & Van Anders, 2011). Clearly, findings relating women's average T levels to their T-drive linkage yield a mixed picture. Yet notably, none of these studies have assessed associations between naturally-occurring day-to-day variation in T and naturally-occurring day-to-day variation sex drive, and hence the present study will make an important contribution to the unanswered question of how average levels of T relate to women's T-drive linkage.

Individual Differences in the Day-to-Day Variability in T

Just as some women have higher average levels of T than others, some women may show larger fluctuations in T than others (Aedo, Nuñez, Landgren, Cekan, & Diczfalusy, 1977), and this variability may influence a woman's T-drive linkage. This possibility is supported by research conducted by Alexander, Sherwin, Bancroft, and Davidson (1990). They investigated whether oral contraceptive users' and nonusers' sex drives decreased during the perimenstrual period (i.e., the period just prior to menses). T levels typically decline during the perimenstrual period, but in oral contraceptive users, T levels remain stable. Sure enough, women using oral contraceptives, who had artificially stable T levels, did not show changes in sex drive during the perimenstrual period, whereas women who were not taking oral contraceptives showed declines in sex drive. Hence, both artificially low T and artificially stable T in the oral contraceptive users may contribute to the lack of change in their sex drive.

Only one study to date has specifically tested whether women who show certain patterns of within-person variability in T show different patterns of between-person associations of T and sex drive. In the aforementioned study by Graham and colleagues (2007), all women showed a considerable reduction in T levels after the administration of oral contraceptives, but these changes were larger in some women than others. As it happened, the women with the largest declines in T were the most likely to show concurrent decreases in sex drive, although this finding fell short of statistical significance. Nonetheless, results suggest that women whose T levels show a greater capacity for variation (whether naturally or in response to experimental treatment) show stronger links between within-person changes in T and changes in sex drive. The most

robust test of this possibility would come from research assessing naturally occurring variation in both T and sex drive. This would allow for the independent measurement of each woman's degree of naturally-occurring daily variability in T, and would permit an examination of whether women with greater overall variability show stronger linkage between daily changes in T and daily changes in sex drive.

Sexual Orientation

To date, no studies have examined the link between T and sex drive in sexual minority (i.e., nonheterosexual) women. Although women with different sexual orientations do not differ in their average levels of gonadal hormones, limited research suggests that the linkage between T and sex drive might vary across sexual orientation subgroups.

First, lesbian, bisexual, and heterosexual women show substantial differences in their sex drive (Lippa, 2007; Lippa, 2006), with bisexual women showing higher levels of sex drive than lesbian and heterosexual women. Moreover, studies have found that the relation between gonadal hormones and sex drive differ across women with varying degrees of same-sex and other-sex attractions. Diamond and Wallen (2011) examined whether changes in same-sex sexual motivation during an ovulation-related estrogen (E) peak was associated with individual differences in women's patterns same-sex attractions. They found that women with different patterns of same-sex attraction showed different degrees of linkage between their sexual motivation and their E levels. Specifically, during the ovulation-related E peak, lesbians showed larger increases in same-sex sexual motivation than bisexual women. This finding raises the possibility that

women with different patterns of same-sex attraction might also show different degrees of linkage between their sexual motivation and their testosterone levels.

Interaction of Between- and Within-Person Variability in the T-Drive Linkage

The current study is the first to simultaneously investigate within-person (i.e., change in a woman's T-drive linkage over time, relative to ovulation) and between-person (i.e., change in the overall T-drive linkage from woman to woman) sources of variation in the T-drive linkage. Examining these factors simultaneously raises the question of whether the aforementioned within- and between-person factors interact to affect the variation in the T-drive linkage.

One possibility is that ovulation-related changes and individual differences independently influence the T-drive linkage. That is, the T-sex drive linkage may prove stronger in some women than others and stronger at some points in the menstrual cycle than others, but between- and within-person differences are orthogonal and do not interact. This would suggest that any changes in T-drive linkage across ovulatory phase are found in all women and that differences in the T-drive linkage associated with individual characteristics (e.g., average sex drive, average T, variability in T, and sexual orientation) are equivalent before, during, and after ovulation. On the other hand, it is possible that the T-drive linkage is stronger in some women than others, but only during certain ovulatory phases (i.e., various periods of ovulation may moderate the effect of individual differences on the T-sex drive linkage). This would indicate that individual differences in the T-sex drive linkage would only be discernible at some points in time,

relative to ovulation. For example, the T-sex drive linkage may be greater for woman with higher T, but only during the period following ovulation. This would be consistent with the Schreiner-Engel et al. (1981) aforementioned finding that women with differences in average T (i.e., high, medium, and low) showed differences in sex drive, but only during the luteal phase. Hence, we plan to conduct exploratory investigations of possible interactions between between-person and within-person variation in the T-drive linkage.

Current Study

The current study uses multilevel random coefficient modeling to test whether day-to-day links between T and sex drive vary within women before, during, and after ovulation and vary across women with different characteristics (specifically, different levels of average sex drive, different levels of average T, different degrees of variability in T, and different sexual orientations). Based on previous research, we hypothesized that among all women, day-to-day associations between T levels and sex drive will be higher during and after the ovulatory portion of the menstrual cycle (operationalized here as the 5-day midcycle period during which estrogen levels peak) than before the ovulatory portion of the cycle. With regard to between-person differences in the T-drive linkage, we hypothesized that, independent of ovulatory timing, higher day-to-day associations between T and sex drive will be found among women with (a) higher overall sex drives; (b) higher average T levels, and (c) greater day-to-day change in their T levels. We also plan exploratory tests for potential differences between heterosexual, lesbian, and

bisexual women in T-drive linkage, as well as exploratory tests for interactions between within-person and between-person predictors of T-drive linkage.

METHOD

Participants

Participants were 51 lesbian-identified, 53 bisexual-identified, and 52 heterosexual-identified adult women recruited from flyers throughout the community, advertisements on Facebook and in a local newspaper, lesbian, gay, and bisexual community events, and classes on gender and sexuality issues taught at local colleges and universities. To maximize homogeneity of the sample with regard to other sources of hormonal variation, we restricted the sample to women under the age of 35 who had regular menstrual cycles and were not taking hormonal birth control or medications known to be associated with subjective sexual desire, such as antidepressants. All participants provided written informed consent that was approved by the University of Utah Institutional Review Board (IRB).

The average age of the present participants was 24.5 years (SD = 4.56) and 89.9% had completed at least 1 year of college. Additionally, 37.8% reported an annual income of less than $25,000, 16.0% reported an annual income of over $55,000. The majority of participants were White (N=136) and 20 of the participants were non-White. Approximately, 19.2% reported a religious preference of Latter Day Saints, 24.3% reported another religious preference, and 56.4% disclosed they were not religious. In all, 63.5% of women in the sample were partnered, 12.8% were married, and 49.4%

considered themselves in a committed lasting relationship.

Procedure

Eligible participants came into the laboratory to complete an initial questionnaire and receive instructions for the "at home" portion of the study. Each participant met with a single research assistant who maintained contact with them throughout the study, administering informed consent, providing regular reminders during the daily diary assessment, and answering any ongoing questions. Participants were instructed to contact their research assistant on the first day they began menstruating. This information was recorded by the research assistant, who prompted the participant to begin their daily diary (described below) 7 days later. The participant completed the daily diary each day before bedtime for 28 days. Diary entries were made online, and data were maintained through a secure server at the primary investigator's institution. The participant logged on each day with a unique username and password, and each entry was time- and date-stamped. Women were provided with paper copies of the diary in case they had trouble accessing the internet or if they did not have internet access at home.

On the third day of the daily diary assessment, women began providing daily saliva samples for the assessment of estrogen and testosterone. Research assistants maintained electronic contact with participants to ensure that they began saliva sampling on the correct day. Participants were instructed to contact their research assistant in the event that they forgot to provide their sample. Each woman was provided with 16 pre-labeled plastic 2 ml centrifuge tubes (14 sample tubes and 2 extras), and they were instructed to passively drool into the tubes in order to provide the saliva samples.

Participants were instructed (and regularly reminded) to provide their saliva sample at the same time each day and to refrain from eating, drinking, smoking, and brushing their teeth at least 1 hour before providing the sample. Participants were instructed to rinse their mouths with plain water 20–90 minutes before providing the sample and to immediately freeze the completed sample. Samples were collected for 14 consecutive days. Following the completion of the study, research assistants conducted home visits to obtain the frozen saliva samples, which were maintained in a frozen state continuously through their delivery to the Kirschbaum laboratory for assay. Participants were compensated $50 for their time.

Measures

At the laboratory, before beginning the daily diary assessment, participants completed an initial questionnaire assessing general features of their sexuality. Sexual orientation was obtained by their sexual identity label and assessing their same-sex and other-sex desires and behaviors were measured using questions from the Sexuality Questionnaire (Brown & Alderson, 2010). Participants were asked about same-sex and other-sex attractions, fantasies, desired behaviors, partners, propensity to fall in love, falling in love in the past year (e.g., "During the past 12 months, to what extent have you experienced sexual fantasies of men [or women] during either masturbation or during sex with a partner?"). Response categories were "none or zero," "low," "moderate," or "high." We then obtained aggregates of both same-sex and other-sex desires and behaviors. If lesbian or heterosexual participants showed similar levels of same-sex and other-sex desires (difference less than 2 points), participants were recoded as bisexual. If

bisexual participants demonstrated a strong preference for one sex over the other (difference of 2 or greater), bisexuals were recoded as either heterosexual (for preference for other-sex attractions) or lesbian (for preference for same-sex attraction).

Additionally, participants answered questions about their overall level of motivation to engage in sexual activity, using the sexual motivation subscale of the Multidimensional Sexuality Questionnaire (Snell, Fisher, & Walters, 1993). This scale asked participants to rate statements such as "I am very motivated to be sexually active" on a 1 to 5 scale, with 1 representing "not at all characteristic of me" and 5 representing "extremely characteristic of me." Note that this trait-level measure of sexual motivation is distinct from the daily measure of sex drive assessed with the daily diary (described below). To avoid confusion, we use the word "drive" to refer to the daily measure and "sexual motivation" to refer to the trait-level questionnaire measures.

The items in the online daily diary were modeled after the Sexual Desire Inventory (Spector, Carey, & Steinberg, 1996). Day-to-day sex drive was assessed with 2 questions on the daily diary, one which asked women to rate how often they had felt sexually aroused, thought about sex, or had a sexual fantasy, and another which asked how often they had found another person attractive. Both questions were rated on a scale from 1-4 (not at all, 1–2 times, 3–4 times, or more than 5 times). Cronbach's alpha for this index was .75. Across the 14 days of diary assessments and 157 participants, 10% of data were missing.

Testosterone (T) and estradiol (E) was obtained using saliva samples that were provided by the participants every morning for 2 weeks. Saliva samples were stored at -20ºC until the time of assay. Samples were shipped (2-day shipping) in insulated

containers with dry ice to Dresden University of Technology in Dresden, Germany for assay. Sampling tubes were centrifuged at 3,000 rpm for 5 min, resulting in mucous compounds being restricted to the lower part of the tube. Salivary E and T concentrations were measured using commercially available chemiluminescence immunoassays with high sensitivity (IBL International, Hamburg, Germany). The intra- and interassay coefficients are below 8% and 11%, respectively. In all, 2% of saliva samples were missing. One participant had multiple days on which her testosterone levels were zero. Because this might indicate an endocrinological condition, this participant was deleted from the sample.

To identify the window of ovulation, we plotted each woman's daily levels of T and E levels. We then identified the ovulatory-related estrogen peak, defined as the peak of E that was followed by the largest decline in E (Roney & Simmons, 2013). The ovulatory window included the 2 days before to the 2 days after the ovulatory-related E peak.

RESULTS

Analytic Strategy

Analyses were conducted with multilevel random coefficient modeling (MRCM, employed with WHLM; Bryk & Raudenbusch, 1992), to represent the nested nature of the data, in which lower level units (daily testosterone and daily sex drive) vary within persons, whereas sexual orientation, average T, variability in T, and sexual motivation (to represent the trait-level sex drive among participants) vary between persons. Graphical representations of the distributions of the data verified that the assumptions for MRCM were not violated. Due to the kurtotic distributions of both T and E levels, logarithmic transformations with a factor of 1 (i.e., logartithm + 1) were used for all analyses.

The Level 1 model predicts each woman's daily sex drive from her daily T and E levels. To assess the effect of ovulation related variability, dummy variables were added to the Level 1 model to represent different stages of the menstrual cycle associated with ovulation, along with interactions between T and these dummy variables. Hence, the Level 1 model has the following structure:

Sex Driveday i, participant j = $\beta 0ij + \beta 1(T)ij + \beta 2(E)ij + \beta 3$(Ovulatory window)$ij + \beta 4$(Postovulatory window)$ij + \beta 5$(Ovulatory window * T)$ij + \beta 6$(Postovulatory period * T)ij + error ij

This model is analogous to calculating a separate regression model for each women, in which the ''sample'' comprises her 14 days of data. The dummy variable for

"Ovulatory window" is coded 1 on the 5 consecutive days during which a woman's estrogen levels were highest, and 0 on all other days. The dummy variable for "Postovulatory window" is coded 1 for all days prior to the ovulatory window, and coded 0 for all other days. Hence, coefficient β3 tests the difference between a woman's sex drive from preovulation to ovulation, and β4 tests the difference between a woman's sex drive from preovulation to postovulation. Following standard practice, T and E levels were ipsatized, or "group centered" around each woman's 14-day mean, so that the coefficient for E (β1) and the coefficient for T (β2), represent the degree to which a woman's day to day deviations from her own average correspond to day to day changes in sex drive. Coefficients β5 and β6 are interaction terms assessing whether the association between T and sex drive varies according to ovulatory period. The coefficient β5 tests whether the T-drive association is stronger or weaker during the preovulatory period than during the ovulatory window and β6 tests whether the T-drive association is stronger or weaker during the preovulatory than the postovulatory period. To test whether the T-drive association is stronger or weaker during the ovulatory period and the postovulatory period, the model is rerun with the ovulatory period entered as the base category. Whereas the Level 1 model tests for overall within-person effects across the entire sample (i.e., whether within-person changes in T are significantly associated with within-person changes in sex drive across the sample as a whole), the Level 2 model examines whether the size and/or direction of these effects varies from woman to woman.

The coefficient of interest is the β1 slope, representing the strength and direction of the daily association between day-to-day changes in T and day-to-day changes in sex drive. The multilevel modeling procedure generates an estimate of the average T-drive

slope (the intercept) and a random effect (the residual of each person's slope). The test for statistical significance of the intercept indicates whether there is, on average, a statistically significant within-person association between daily T and daily sex drive. The test for statistical significance of the random effect indicates whether there is significant between-person variability in the within-person association between T and sex drive.

To test the overall within-person association between T and sex drive and to test whether that T-drive association varied significantly from woman to woman, we first calculated an unconditional model, which estimated only the Level 1 effects of T and E as a function of the intercept and the random effect. To assess whether the T-drive association differed among women who varied in their sexual motivation, average T levels, variability in T, and sexual orientation), these variables were entered at the β1 slope of the unconditional model (i.e., the model that calculated only the Level 1 effects of T and E). Because sex drive is the outcome in our model, we could not specifically test whether average levels of sex drive moderate the T-sex drive linkage. Hence, individual differences in trait sex drive (henceforth, referred to as sexual motivation) was used. To assess how the aforementioned within-person and between-person effects may interact with one another to shape T-drive linkage, we added the between-person moderators (i.e., sexual motivation, average T levels, variability in T, and sexual orientation) to the model that estimated the Level 1 effects of T during various ovulatory phases, following the structure below:

$$B1j(\text{i.e., T-drive slope during the preovulatory period}) = \gamma 10j + \gamma 11(\text{Lesbian})j + \gamma 12(\text{Heterosexual})j + \gamma 13(\text{Sexual Motivation})j + \gamma 14(\text{Average T})j + \gamma 15(\text{Standard}$$

Deviation of T)j + error1j

This Level 2 model calculates whether women's T-drive association during the baseline ovulatory period (i.e., the preovulatory period) differs among women who vary in sexual motivation, average T levels, variability in T, and sexual orientation. Sexual orientation was represented in 2 dummy codes (lesbian and heterosexual), so that the base group was bisexual women (tests for differences between lesbian and heterosexual women were achieved by rerunning analyses with heterosexuals as the base category). Hence, the intercept, γ10j, tests whether the T-drive association during the preovulatory period is significant for bisexual women. The coefficient γ11 tests whether the T-drive association during the preovulatory period differs between bisexual and lesbian women, and γ12 tests whether the T-drive association during the preovulatory period differs between bisexual and heterosexual women. Following standard procedures, sexual motivation, average T levels, and variability in T were grand-mean centered. The coefficient, γ13 tests whether women who have higher T-drive associations during the preovulatory period are more or less sexually motivated. The coefficient, γ14 tests whether the women who have higher T-drive associations during the preovulatory period have higher or lower average levels of T and γ15 tests whether women who have higher T-drive association during the preovulatory period have more or less variability in their T across the 2 week period.

To test whether the T-drive association was related to the above-mentioned variables at the ovulatory and the postovulatory periods, the model is rerun with the ovulatory and the postovulatory periods, respectively, entered as the base category. In order to allow the γ coefficients of the β1 T-drive slope to vary at the different ovulatory

phases, the between-person characteristics (i.e., sexual motivation, average T levels, variability in T, and sexual orientation) were also entered at β5, representing the difference in the T-drive association from the preovulatory period to the ovulatory window and β6, representing the difference in the T-drive association from the preovulatory period to the ovulatory window. (Omitting these effects at β5 and β5 would tell the model that these effects are equivalent across ovulatory phases and would result in obtaining the same magnitude and direction of effects when the model was run with different ovulatory phases as the baseline category.)

We calculated the proportion of variance explained for each model following recommendations of Raudenbush and Bryk (2002). To calculate the effect size of each model, we subtracted the variance component of the current model from that of the unconditional model and divided that value by the variance component of the current model. Significant Level 2 effects (indicating moderation of the Level 1 T-drive slope by Level 2 variables) were followed up with simple slope tests aimed at establishing how the day-level association between T and sex drive varied at high and low levels of the moderator. To characterize the full range of individual differences in T-drive linkage, we tested simple slopes at both 1 and 2 standard deviations above/below the mean of each continuous moderator (Jaccard & Turrisi, 2003).

Demographic Characteristics and Bivariate Associations

Table 1 (located at the end of the chapter, along with other tables and figures) presents means and standard deviations among the primary study variables across the 14-day period, as well as the means and standard deviation of these variables prior to,

during, and following the ovulatory window. Correlations of the primary study variables across the 14-day period (see Table 2) indicated that women who had higher average T levels also had higher average E levels, but less variability in their T. Additionally, across the 14-day assessment period, lesbians and bisexuals had higher sex drives $F(2,154)=6.86$, $p<.01$, and sexual motivation, $F(2,154)=9.69$, $p<.01$, than heterosexuals. No other differences emerged among lesbian, bisexual, and heterosexual women (all F's<2.8 and p's$>.06$).

Do Women Show Variation in the Link between Daily T and Daily Sex Drive?

To test for the degree of person-to-person variation in the association between daily T and daily sex drive, we ran a model predicting, at Level 1, each woman's daily sex drive from her corresponding daily T and E. The overall T-drive slope (representing the association between day-to-day changes in T and day-to-day changes in sex drive) was not significant ($b=.09$, $SE=.1$, $p>.2$). Yet, there was a significant random effect of the T slope ($\chi 2(156, N=157)=191.04$, $p=.03$) indicating that the association between daily T and daily sex drive across the 14-day period varied significantly across women. Inspection of the distribution of the T-drive slopes (using the empirical bayes residuals generated by HLM) indicated that approximately 35.7% of participants showed positive T-drive slopes (such that increases in T corresponded to increases in sex drive) and 23.6% unexpectedly showed negative T-drive slopes (such that increase in T corresponded to decreases in sex drive). The existence of both positive and negative T-drive slopes explains why the overall Level 1 T-drive slope was not significant, since the

positive and negative slopes effectively cancelled each other out at the sample level. Having confirmed that women vary in their T-drive linkage, we proceeded to test our hypotheses that the women's T-drive linkage would change (1) across ovulatory periods and (2) across individuals with varying levels of sexual motivation, average T levels, and variability in T, and of different sexual orientations.

Does Women's T-Drive Linkage Change across Ovulatory Phases?

To test whether women's T-drive linkage increased over time, such that women's T-drive linkage would be higher during and following the ovulatory window than their T-drive linkage before the ovulatory window, we ran a model that included, at Level 1, dummy variables representing the ovulatory phases, and interaction terms between each ovulatory phase and T (we also tested for possible interactions between the ovulatory phases and E, and no such interactions were detected). We found that women's T-drive slope did not differ prior to the ovulatory window than during the ovulatory window (b=.19, SE=.18, p>.2). However, women's T-drive slope was stronger following the ovulatory window than prior to (b=-.64, SE=.21, p<.01) or during (b=-.45, SE=.21, p=.04) the ovulatory window. We then conducted a follow-up test to determine the specific magnitude of T-drive linkage before, during, and after the ovulatory window. We found that women showed no association between T and sex drive prior to (b=-.11, SE=.12, p>.2) or during (b=.08, SE=.15, p>.2) the ovulatory window. In contrast, we found women showed a significant T-drive slope following the ovulatory window, such that increases in T corresponded to increases in sex drive (b=.53, SE=.18, p<.01).

Additionally, we found that ovulation-related timing accounted for 18.93% of the

variance in the T-drive slope, indicating that 18.93% of the unexplained variance in the T-drive slope is due to ovulation-related timing. Moreover, the random effect of the T-drive slope dropped in magnitude, but remained significant, $\chi 2(156, N=157)=186.03$, $p=.05$. This suggested that additional variables may further explain the variation in T-drive linkage. Hence, we examined whether the T-drive linkage varied systematically across women, independent of ovulatory phase.

Does Women's T-Drive Linkage Vary Systematically across Women?

To assess whether the T-drive linkage across the 2-week period varied systematically across persons, we examined whether individual differences in sexual motivation, average T, variability in T, and sexual orientation moderated the T-drive slope across the 14-day period. Consistent with our hypothesis, we found that women who were more sexually motivated showed higher T-drive slopes ($b=.19$, $SE=.06$, $p<.01$). Follow-up tests showed that the T-drive slope was not significant among women with higher or lower levels of sexual motivation (i.e., 1 SD above and below the mean; all b's$<.22$, p's$>.18$). One reason for these null results is that the differences in the T-drive slope may be limited to women with extreme levels of sexual motivation. Although it is not standard practice, assessing extreme levels of sexual motivation may provide clinically-relevant information, given that women with hypoactive sexual desire disorder have extremely low levels of sexual motivation. Hence, we conducted ancillary analyses at 2 SD above and below the mean. Among women with very low sexual motivation (2 SD below the mean), increases in T corresponded to decreases in sex drive ($b=-.46$, $SE=.22$, $p=.04$). Yet, among women who were extremely sexually motivated (2 SD above

the mean), increases in T corresponded to increases in sex drive (b=.45, SE=.21, p=.03).

The effect size for this model indicated that 16.27% of the unexplained variance in the T-drive slope was due to individual differences in the above-mentioned characteristics. Moreover, the random effect of the T-drive slope became nonsignificant, $\chi 2(156, N=157)=177.14$, p=.07. This suggests that the variance in the T-drive slope is largely explained by individual differences in the various sexual characteristics.

Does Ovulatory Phase Moderate the Effect of Individual Characteristics on the T-Drive Linkage?

Next, we turned to exploratory investigations of possible interactions between within-person and between-person sources of variability in the T-drive slope. The results of these analyses are presented in Table 3 (because bisexuals were used as the reference group, Table 3 presents estimates among bisexuals.)

Sexual Motivation

Although the relation between sexual motivation and the T-drive slope did not significantly change across ovulatory phases (b's<.16, p's>.09), sexual motivation was significantly associated with the T-drive linkage during the ovulatory window, but not before or after the ovulatory window (see Table 3). During the ovulatory window, women with higher sexual motivation only showed significantly higher T-drive linkage during the ovulatory window (b=.30, SE=.13, p=.02). Follow-up simple slope tests indicated that the T-drive slope was not significant among women who had higher or lower levels of sexual motivation (i.e., 1 SD above and below the mean; b's<.38, p's>.2). For the same

reasons as above, we conducted ancillary analyses of women with extreme levels of sexual motivation. We found that only women who were extremely sexually motivated (i.e., 2 SD above the mean) showed a significant T-drive linkage during the ovulatory window, such that increases in T corresponded to increases in sex drive (b=.74, SE=.37, p=.04). Figure 1 graphically depicts differences in T-drive slopes before, during, and after the ovulatory window among women with high, medium, and low levels of sexual motivation, (defined as 1 SD above and below the mean).

Average T Levels

There was a significant interaction between ovulatory timing and average T levels in predicting T-drive linkage ($b_{\text{before vs. after}}$=2.66, SE=.15, p<.01; $b_{\text{during vs. after}}$=2.15, SE=.84, p=.01). Average T levels were significantly associated with T-drive linkage prior to and after the ovulatory window, but not during the ovulatory window (see Table 3). Prior to the ovulatory window, women who had higher levels of average T had lower estimates of the T-drive slope (b=-.95, SE=.46, p=.04). Follow-up simple slope tests indicated that women with higher average T levels (i.e., 1 SD above the mean) showed a significant inverse T-drive slope (b=-.46, SE=.23, p=.05), such that increases in T corresponded to decreases in sex drive. Yet, women with lower average T levels did not show a significant T-drive slope (b=-.11, SE=.21, p>.2).

Following the ovulatory window, women who had higher levels of average T had higher estimates of the T-drive slope (b=1.72, SE=.43, p<.01). Follow up simple slope tests indicated that women with mean or higher average T levels showed a significant T-drive slope ($b_{\text{mean T}}$=.71, SE=.30, p<.02; $b_{\text{high T}}$=1.02, SE=.32, p<.01), such that increases

in T corresponded to increases in sex drive. In contrast, women with lower average T levels (i.e., 1 below the mean) did not show a significant T-drive slope (*b*=.40, *SE*=.30, *p*>.17). Figure 2 graphically depicts differences T-drive slopes before, during, and after the ovulatory window among women with high, medium, and low levels of average T (defined as 1 SD above and below the mean).

Variability in T

The relation between variability in T and the T-drive linkage did not significantly change across ovulatory phases (*b*'s<.3.54, *p*'s>.15). However, variability in T was significantly associated with the T-drive linkage prior to the ovulatory window, but not during or after the ovulatory window (see Table 3). Women with more variability in T had significantly lower estimates of the T-drive linkage prior to the ovulatory window (*b*= -3.97, *SE*=1.6, *p*=.03). Follow-up simple slope tests indicated that women with more variability in T (i.e., 1 SD above the mean) showed a significant inverse T-drive slope (*b*=-.46, *SE*=.23, *p*=.05), such that increases in T corresponded to decreases in sex drive. Yet, women with less variability (i.e., 1 SD below the mean) in T did not show a significant T-drive slope (*b*=-.01, *SE*=.26, *p*>.2). Figure 3 graphically depicts differences in T-drive slopes before, during, and after the ovulatory window among women with high, medium, and low levels of variability in T (defined as 1 SD above and below the mean).

Sexual Orientation

There was a significant interaction between ovulatory timing and sexual orientation in predicting T-drive linkage ($b_{\text{before vs. after}}$=-1.27, *SE*=.53, *p*=.02). Lesbian, heterosexual, and bisexual women significantly differed in their T-drive linkage prior to and following the ovulatory window, but not during the ovulatory window (see Table 3). Prior to the ovulatory window, heterosexual women had higher estimates of the T-drive slope than bisexual women (*b*=.74, *SE*=.30, *p*=.02) and lesbians (*b*=-.60, *SE*=.27, *p*=.03). Yet, the T-drive slope of bisexual women did not differ from that of lesbian women (*b*=.14, *SE*=.25, *p*>.2). Follow-up simple slope tests indicated heterosexuals displayed a significant T-drive slope (*b*=.45, *SE*=.23, *p*=.05), such that increases in T corresponded to increases in sex drive. Yet, lesbians and bisexuals did not show a significant T-drive slope (bisexuals: *b*=-.28, *SE*=.21, *p*>.2; lesbians: *b*=-.15, *SE*=.17, *p*>.2).

Following the ovulatory window, lesbians had higher estimates of the T-drive slope than heterosexual women (*b*=.77, *SE*=.37, *p*=.04). However, the T-drive slope of bisexual women did not differ from that of lesbian or heterosexual women (*b*'s<.24, *p*'s>.2). Follow up simple slope tests indicated that lesbian and bisexual women showed a significant T-drive slope (lesbians: b_{lesbian}=.95, *SE*=.32, *p*=.03; b_{bisexual}=.71, *SE*=.30, *p*=.02), such that increases in T corresponded to increases in sex drive. In contrast, heterosexual women did not show a significant T-drive slope (*b*=.18, *SE*=.35, *p*>.2). Figure 4 graphically depicts differences in T-drive slopes before, during, and after the ovulatory window among lesbian, bisexual, and heterosexual women.

Taken together, between-person and within-person sources of variability accounted for 55.15% of the variance in T-drive slopes. Moreover, the random effect of

the T-drive slope was well outside of the range of significance, $\chi 2(156, N=157)=160.08$, $p>.2$, suggesting that the current model accounted for nearly all the variance in T-drive slopes that can be explained.

Table 1

Descriptive Statistics for Study Variables

Variable	Overall M(SD)	Preovulatory Period M(SD)	Ovulatory Window M(SD)	Postovulatory Period M(SD)
Drive	2.58(.52)	2.57(.55)	2.6(.61)	2.58(.68)
T[a]	1.30(.26)	1.30(.27)	1.33(.27)	1.28(.29)
E[a]	.80(.11)	.74(.13)	.87(.13)	.81(.13)
Variability in T[b]	.18(.07)	.16(.08)	.17(.09)	.15(.11)
Sexual Motivation	3.25(1.22)	--	--	--

Notes: [a] Transformed using logarithm+1 [b]. Assessed by standard deviation across days

Table 2

Correlations Among Study Variables

Variable	1	2	3	4
1. Drive				
2. Average T	.08			
3. Variability in T	.10	-.34**		
4. Average E	.05	.46**	-.27**	
5. Sexual Motivation	.29**	-.01	.12	.09

Notes: *p<.05, **p<.05

Table 3

T-Drive Linkage during each Ovulatory Phase as a Function of Sexual Orientation, Sexual Motivation, Average T levels, and Variability in T.

Model Term	Coefficients of DV	Difference from DV to the ovulatory window	Difference from DV to postovulatory period
DV: T-drive slope during the preovulatory period			
Intercept	-.28(0.21)*	.30(0.42)	1.00(0.38)**
Lesbian	.14(0.25)	.10(0.43)	.10(0.49)
Heterosexual	.74(0.30)*	.46(.46)	-1.27(0.53)*
Sexual Motivation	.14(0.08)	.16(0.15)	-.19(0.15)
Average T	-.95(0.46)*	.51(0.72)	2.66(0.63)**
Variability in T	-3.97(1.67)*	.66(2.59)	3.54(2.46)
DV: T-drive slope during to the 5-day ovulatory window			
Intercept	.01(0.31)		.70(0.46)
Lesbian	.24(0.33)		-.00(0.54)
Heterosexual	.28(0.41)		-.82(0.58)
Sexual Motivation	.30(0.13)*		-.34(0.16)*
Average T	-.44(0.56)		2.15(0.66)**
Variability in T	-3.32(2.01)		2.88(2.67)
DV: T-drive slope during the postovulatory period			
Intercept	.71(0.30)*		
Lesbian	.24(0.39)		
Heterosexual	-.54(0.42)		
Sexual Motivation	-.04(0.12)		
Average T	1.72(0.43)**		
Variability in T	-.43(1.85)		

Notes: *p<.05, *p<.01

Figure 1

T-Drive Linkage during each Ovulatory Phase as a Function of Sexual Motivation

(Measured in Standard Deviations)

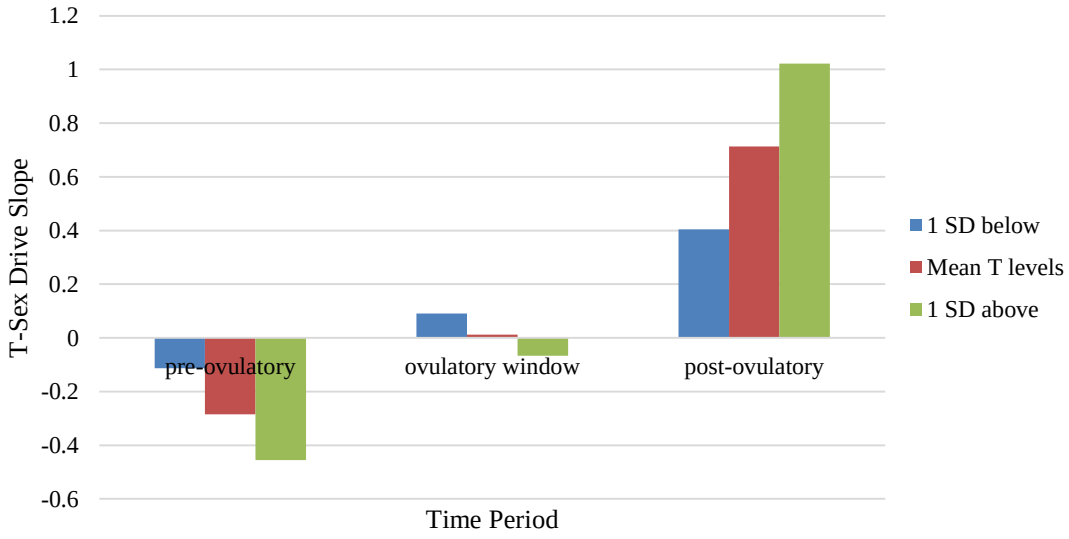

Figure 2

T-Drive Linkage during each Ovulatory Phase as a Function of Average T levels

(Measured in Standard Deviations)

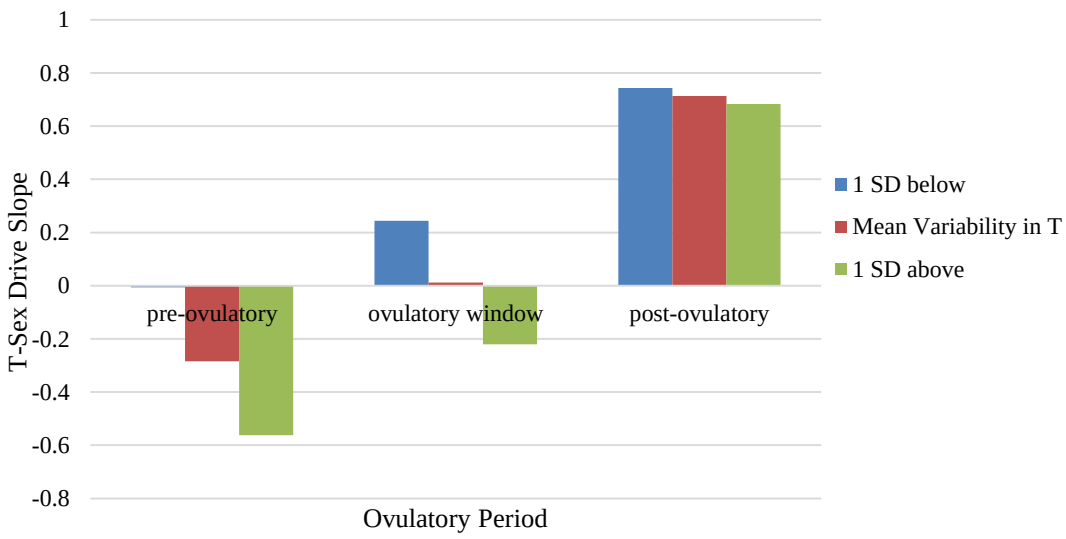

Figure 3

T-Drive Linkage during each Ovulatory Phase as a Function of Variability in T (Measured in Standard Deviations)

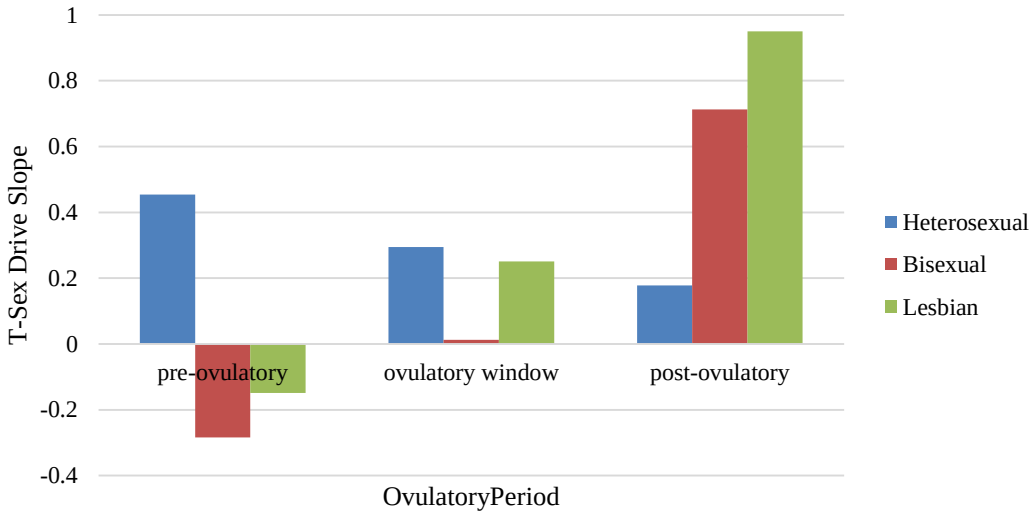

Figure 4

T-Drive Linkage during each Ovulatory Phase as a Function of Sexual Orientation

DISCUSSION

The current study makes a significant contribution to our understanding of female sex drive by clarifying the specific conditions under which higher levels of day to day testosterone predict higher levels of sex drive. Specifically, we tested for 2 forms of variability in that association: (1) within-person variability related to ovulatory timing and (2) between-person variability related to individual differences in sexual motivation, average T levels, variability in T, and sexual orientation. As predicted, we found that a woman's T-drive linkage varied significantly as a function of ovulatory timing. After ovulation (as determined by women's estrogen peak), T-drive linkage was positive and significant, meaning that daily increases and decreases in T were related to corresponding daily increases and decreases sex drive. Yet this was not the case prior to or during ovulation. With regard to between-person variability, we found no overall associations between a woman's T-drive linkage and her overall sexual motivation, average T level, degree of variability in T, or sexual orientation. However, we found that each of these variables interacted with ovulatory timing to predict T-drive linkage. Prior to the ovulatory window, we found that heterosexual women showed significant T-drive linkage, whereas lesbian and bisexual women did not. Also during this period, inverse T-drive linkage (i.e., higher daily levels of T predicting lower daily sex drive) was found among women with high average T levels or greater overall variability in T. During the

ovulatory window, the only women showing significant T-drive linkage were those with extremely high levels of sexual motivation. Following the ovulatory window, nearly all women showed significant T-drive linkage, with the exception of heterosexual women and those with low T levels. These findings demonstrate the complexity of the relationship between women's T levels and their sex drive, and they make an important contribution to our basic understanding of the endocrinology of female sex drive as well as to the clinical treatment of women with hypoactive sexual desire disorders.

Ovulatory Changes Underlie Differences in the T-Drive Linkage

Researchers using a variety of methodologies and study designs (e.g., assessing the relation between average T and average sex drive, experimentally reducing or increasing T and observing subsequent changes in sex drive) have previously found mixed results regarding the link between T and sex drive. In some cases, changes in T appear to predict corresponding changes in sex drive, but in other cases no such association is found, and in some cases an inverse association is found. The results of the present study provide an explanation for this mixed pattern of findings: Specifically, the linkage between T and sex drive varies both within women and also across women. Without properly accounting for such variation, researchers may find significant T-drive linkage or insignificant T-drive linkage depending on the population of women that they study and also depending on when (relative to ovulation) these women are assessed.

We predicted that women's T-drive linkage would vary as a function of ovulatory timing, based on previous research showing that both T and sex drive reach a peak around the time of ovulation, and reach a low point afterwards (e.g., Burger, 2002; Roney

& Simmons, 2013). Previous research has also found that women with higher average T levels tend to have higher subjective arousal during ovulation but higher physiological arousal following ovulation (Schreiner-Engel et al., 1981). Hence, we hypothesized that the link between T and sex drive would be stronger during and after ovulation than before ovulation, and this was partially confirmed. Although women did not show significantly greater T-drive linkage during ovulation than prior to ovulation, T-drive linkage was stronger after ovulation than during or prior to ovulation.

One reason that the T-drive linkage is strongest following ovulation may be related to menstrual cycle fluctuations of other gonadal hormones (e.g., estrogen). Researchers have demonstrated that during fertile periods (i.e., prior to and during ovulation) there is a tighter coupling between estrogen (E) and female sexual behavior and motivation (Wallen & Zehr, 2004). Given that rises in E, not T, directly influences psychophysiological changes associated with ovulation, it is possible during fertile periods, the tighter coupling of E with female sex drive may obscure the relation between T and sex drive, such that T may not have any additional influence on women's sex drive. Yet, during the nonfertile periods (i.e., following ovulation), the weaker coupling between E and female sexual motivation may allow fluctuations in T to play a more influential role in women's sex drive.

These results provide insight into existing gender differences regarding the hormonal correlates of sex drive. Whereas men's low E levels allow T to be "the" hormone of desire, women's sex drive is associated with both E and T, suggesting that women have 2 hormones of desire. Yet, the manner in which T and E interact to jointly shape ongoing change in sex drive is not yet fully understood. Much is to be learned

about how different patterns of variability in T and E across the menstrual cycle inform variability in sex drive. A strength of the present study is the fact that it assessed both T and E and all estimates of the T-drive linkage controlled for the influence of E. Thus, the current study has made an important contribution by showing that even after controlling for E levels, the link between T and sex drive changes relative to ovulation. Hence, future research investigating the contribution of T to female sex drive should take variability in E and the timing of assessment into account.

With regard to clinical applications, these results indicate that when treating women with low sex drive via exogenous administration of T, medical professionals should assess ovulatory changes in sex drive, and should pursue a treatment approach that takes such variation into account. For example, if a woman reports that her sex drive is lowest (or most distressing) during the latter part of the menstrual cycle (i.e., after ovulation), then T therapy might be a suitable option. Yet, T therapy administered prior to or during ovulation may prove ineffective for some women.

Women's T-Drive Linkage is Associated with Different Sexual Characteristics during Different Phases of the Ovulatory Cycle

We hypothesized that between-person differences in T-drive linkage would be related to women's overall sexual motivation, their average T levels, their overall variability in T, and their sexual orientation. These predictions were confirmed, but all of the predicted effects were moderated by ovulatory timing. In other words, the between-person characteristics that predicted T-drive linkage during ovulation were different from the between-person characteristics that predicted T-drive linkage before or after

ovulation.

Prior to the ovulatory window, we found that differences in the T-drive linkage were associated with multiple individual difference domains, explaining why we found no overall significant association between T and sex drive during the preovulatory period. We found that heterosexual women showed a positive T-drive linkage, but lesbian and bisexual women did not. Given that no prior research has examined whether sexual orientation is related to differences in the T-drive linkage, we considered these analyses exploratory. Given the interpretation that we offered earlier for the fact that women's T-drive linkage, on average, is highest after ovulation, the moderating effect of sexual orientation suggests that heterosexual women's T-drive linkage may be less obscured by the competing influences of E on sex drive. Rather, hetoersexual women's T-drive linkage might be facilitated by high levels of E. However, this interpretation is speculative, and future research should seek to elucidate why lesbian, bisexual, and heterosexual women differ in their T-drive linkage across the menstrual cycle.

Our results lend important insight into Alexander et al. (1990)'s hypothesis that there are ceiling effects for T, such that increases in T do not have appreciable effects on sex drive once a certain threshold T level has already been reached. According to this logic, we should find a significant T-drive linkage among women whose average T levels are quite low, but not among women whose average T levels are quite high. Yet, this was not what we found. Rather, we found that whereas women with low average T levels showed no association between T and sex drive prior to the ovulatory window, women with high average T levels showed a negative T-drive linkage, indicating that on days before the ovulatory window when T increased, their sex drive decreased.

Similarly, we also found that women with more variability in T levels showed an inverse T-drive linkage prior to the ovulatory window. This finding was surprising, given that we hypothesized that women with more variability in T would show a higher T-drive linkage. This prediction was based on the Graham et al. (2007) finding that women who showed the largest decreases in T after taking hormonal contraceptives showed the strongest links between reductions in T and reductions in sex drive. Ours is not the first study to find a significant inverse relationship between T and sex drive, and although this particular finding was unexpected, we address potential explanations for this finding below.

During ovulation, the majority of women showed no linkage between their daily T and their sex drive, but this was moderated by sexual motivation. Only women with extremely high levels of sexual motivation showed a significant T-drive linkage during the ovulatory window, such that daily increases in T were associated with daily increases in sex drive. This finding was consistent with our hypothesis that women with higher levels of sexual motivation would have higher T-drive linkages. Hence, results support the logic that women with extremely high levels of sexual motivation may be more susceptible to a variety of influences, including hormonal changes associated with ovulation and day-to-day changes in T. To further confirm this hypothesis, more research is needed to determine whether women who have extremely high levels of sexual motivation have sex drives that are more susceptible to changes in other psychological or neuroendocrinological factors (e.g., increases in positive affect, changes in psychophysiology, etc.). Following ovulation, the majority of women showed a positive T-drive linkage, with the exception of 2 groups: heterosexual women and women with

low average T levels. Although heterosexual women showed a positive T-drive linkage prior to ovulation, their T-drive linkage was not significant following ovulation.

Collectively, these unexpected interaction effects demonstrate the importance of considering both within-person and between-person sources of variability in T-drive linkage. Notably, our findings concord with previous research showing that women with different patterns of stability in sexual orientation showed different patterns of association between sexual motivation and ovulation-related increases in estrogen levels (i.e., Diamond & Wallen, 2011). Given that most previous research on T and sex drive has used exclusively heterosexual samples, the findings of the present study demonstrate the importance of including sexual-minority women.

Moreover, the findings of the present study suggest that among women with low average T levels, changes in T plays a minimal role in their sex drive. These results concord with prior research demonstrating that women not on oral contraceptives (who have higher T) are more likely to show increases in T in response to erotic stimuli than women taking oral contraceptives (have lower levels of T; Goldey & Van Anders, 2011). However, our results are inconsistent with prior research demonstrating that administering exogenous T to low-T women reliably increases women's sex drive (e.g., Goldstat et al., 2003; Krapf & Simon, 2009). One possible reason for this inconsistency is that the link between changes in T and changes in sex drive are made manifest only above a certain level of T. Hence, administering exogenous T to low-T women may push their T levels over this critical level, enabling changes in T to correspond with changes in sex drive. Future research should explore this possibility.

Inverse T-drive Linkage

Perhaps one of the most surprising findings in the study is the fact that some women showed an inverse association between daily T and daily sex drive, such that increases in T were associated with decreases in sex drive. Such a pattern runs directly counter to the longstanding model of T as the "hormone of desire." Yet, the current study is not the first to document that some women show negative associations between T and sex drive. For example, Graham and colleagues (2007) found that one-third of their sample showed increases in sex drive following of a reduction in T. Instead of considering these woman as a separate subgroup, they grouped them with women who showed no change in their sex drive as a result of a reduction in T. Yet, such a grouping may be inappropriate. Our results suggest that women who showed an inverse T-drive linkage prior to ovulation are distinct from the women who showed no T-drive linkage. What do we know about such women?

Only 2 researchers have attempted to understand cases of inverse T-drive linkage. Heiman et al. (2011) found that among women with HSDD, women who had higher levels of T had less sexual arousal in response to erotic stimuli. They argued that women with lower levels of sexual motivation may have undergone changes in receptor density or function that balances the endocrine system to be more "preparatory" for sexual response. From this perspective, increases in sex drive may be interpreted as undesirable, and their endocrine system may attempt to compensate by slowing the release of T. Similarly, Van Anders (2012) hypothesized that T may have a negative link with sexual desire when T is released from the adrenal glands (rather than the ovaries). This hypothesis was based on the fact that the adrenal glands concurrently release cortisol, the

"stress hormone," which has been shown to be associated with decreases in sexual functioning (Hamilton, Rellini, & Meston, 2008).

Similar to Heiman et al. (2011), we also found that women with very low levels of sexual motivation showed a negative T-drive linkage across the 14-day period, but this became nonsignificant when we included ovulatory phase into the model. Our results indicated that the inverse T-drive linkage only occurs for some women (i.e., women with higher average T levels and more variability in T) prior to ovulation. Using Heiman et al. (2011) and Van Ander's (2012) interpretations would suggest that prior to ovulation, stress-related responses (either through appraisal of sex drive or cortisol reactivity) may result in an inverse association between daily T and sex drive. Yet, prior research examining menstrual cycle variability in women's stress responses (as indicated by cortisol release and subjective reports of stress) suggests that women's hormonal stress responses are higher during the luteal phase (following ovulation) than the follicular phase (Altemus, Roca, Galliven, Romanos, & Deuster, 2001; Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). Moreover, previous research has found that T down regulates the stress response (Hermans et al., 2007). Hence, it is not likely that the difference in women's stress responses across the menstrual cycle underlies why some women have a negative T-drive linkage prior to ovulation. Overall, the phenomenon of inverse T-drive linkage does not appear to be artifactual (given that is has emerged across several independent studies) and deserves close scrutiny, particularly for its potential relevance for the treatment of sexual desire disorders.

Limitations

The current study had several limitations. First, the assessing the link between T and sex drive was limited to the middle 2 weeks of the cycle. Hence, it remains unknown whether changes in the T-drive linkage are specific to variation in gonadal hormones during the middle 2 weeks of the cycle versus across the entire menstrual cycle. However, because T levels fluctuate the most during the middle 2 weeks of the cycle, the most robust test of within-person change in the T-drive linkage likely involves the middle 2 weeks of the cycle. Moreover, we maintained a sufficient number of observations to obtain estimates of the T-drive linkage across the 14 day period, as well as prior to, during, and following the ovulatory window. Second, the current study inferred ovulation by assessing the estrogen peak during the fertile period (menstrual cycle days 9-16). This measure of ovulation was suboptimal as we did not have measures of an LH surge, or progesterone levels to ascertain ovulation. Nonetheless, measuring an ovulation related E-peak is more viable than using counting day measures of ovulation, which assumes that ovulation happens on the same day (i.e., at day 15) for every woman. Third, the current study is correlational, and thus, we cannot interpret the direction of our effects (i.e., the effect of T on sex drive vs. the effect of sex drive on T). However, by not assuming a directional pathway, our results can provide important contributions to research examining the effect of T on sex drive and to research examining the effect of sex drive on T.

The current study also had a number of strengths. Assessing the day-to-day association between T and sex drive allowed us to address both within-person and between-person variation in the T-drive linkage. These factors have not been explored in

prior research, given that previous studies have typically taken very few measurements of T and sex drive. Additionally, by controlling for E levels, we were able to determine that changes in the T-drive linkage relative to ovulation are independent of the effects of E. Additionally, to our knowledge, this is the first study that has examined the link between T and sex drive among a large sample of sexual minority and heterosexual women and, thus, represents an important contribution to both the study of T-drive linkage and the study of sexual orientation.

Conclusion

For decades, T has been known as the "hormone of desire." Yet, as researchers become more aware of the inconsistencies in the link between T and sex drive, this assumption is being challenged (e.g., see Brotto, Petkau, Labrie, & Basson, 2011). The current study has provided important insight into when and for whom T is the "hormone of desire." Although this was not a clinical sample and exogenous administration and endogenous levels of T may operate differently, our results provide important insights relevant to treating women with low sex drives via T administration. Arguably, women who have a higher T-drive linkage would benefit more from T-therapy (i.e., administration of exogenous T). Hence, medical providers should pursue a treatment approach that takes both within-person and between-person variation into account. For example, if a heterosexual woman reports that her sex drive is lowest (or most distressing) during the earlier part of the menstrual cycle (i.e., before ovulation), then T therapy might be a suitable option. Yet, T therapy administered during or following ovulation may prove ineffective for heterosexual women.

Our results also have important implications for our basic understanding of women's sex drive, indicating another facet in which female sexuality is highly variable (Bancroft & Graham, 2011; Baumeister, 2000; Diamond, 2008). Our results demonstrated that women's sex drive does not have the same hormonal substrates across the menstrual cycle. Moreover, the manner in which the T-drive linkage changes across the menstrual cycle varies for different women. T may be associated with sex drive among some women during certain ovulatory phases, but not others and T is inversely associated with sex drive among some women during certain ovulatory phases. Hence, T may be "the hormone of desire," but only in some women, some of the time.

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